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# Innovative uses of rain screen cladding. CFD and gas dispersion analysis of a prototype

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**Abstract**

In this work, both CFD and $CH_4$ dispersion analysis in rain screen cladding were carried out, in order to reduce the visual impact of Natural Gas distribution network in civil buildings ensuring high safety standards. In the first part of the work it was conducted the parametric analysis in order to identify the main physical parameters that influence the air velocity in air-gap. Subsequently, CFD simulations were carried out in order to evaluate how the geometric and constructive characteristics can influence the air velocity inside the cavity. In particular, were realized both 2D and 3D models, and was used Ansys Fluent 6.3 software. Finally, Natural Gas dispersion analysis was carried out, in order to evaluate the safety against explosive atmosphere.


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*Keywords*: CFD analysis; rain screen cladding; natural gas dispersion.

## 1. Introduction

This research shows a preliminary study aimed at evaluating the possibility to install a gas distribution network inside a ventilated cavity. It is necessary to ensure high safety standards against explosive atmosphere. In this stage of the study, some numerical analysis were conducted through both Parametric and fluid dynamic analysis. The European energy strategies, such as Europe 2020, promote the greenhouse gas emissions reduction and the increase in energy efficiency. According with it, the design of buildings must comply with these approach, using the best available techniques as proposed in “Eco-

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architecture and sustainable mobility: an integrated approach in Ladispoli town" [1]. In agreement with it, the Europe government policy promotes the efficiency generation systems and eco friendly fuels. Regarding to the energy saving, many authors have investigated on Natural Gas CHP systems. This technological solution, in many applications, guarantees energy consumption reductions and avoids greenhouse gases emissions. In the literature there are many studies regarding new fuels, as well as hydro methane. This fuel, used in CHP systems, allows to avoid carbon emissions [2] [3]. In order to produce Hydrogen for Natural Gas enrichment, with an eco-friendly approach, renewable electricity can be used [4]. However, the hydromethane is currently mainly used in the experimental works, similar environmental features are guaranteed by Natural Gas. Natural Gas plays an increasingly important role in the European energy supply and especially in Italy. In the GSE Database (Italian Energy Services Managing Holder) [5], we can see how, in the period 2011-2012, Natural Gas accounts for about 40% of the national energy mix. This record is due both to the easy availability of this fuel and to his high calorific value, compared to competing fuels. These aspects make it particularly flexible for use in the civil field. Natural Gas is widely used in the civil sector, thanks to its heating value (LHV) and a network distribution currently spread throughout the territory. Moreover, from the environmental point of view, the Natural Gas CO2 emissions are the lowest among the equivalent fuels. In fact its FE emission factor is equal to 0,002 t $CO2/m^3$ [6]. Recently, in Europe and USA, this resource is also used for the feeding of electrical appliances, as for example refrigerators, washing machines, dryers, dishwashers, electric heat pumps, outdoor kitchens and BBQs, pool heaters and more. In this context, the general aim is to make possible the use of the Natural Gas (from here N.G.) as the only energy source for both, air-conditioning of the building, and power supply of a large part of the electromotive equipment. This approach improves the energy efficiency of buildings. So the spread of an efficient N.G. supply network is desirable in any type of building. Considering old buildings, in the literature there are specific studies about innovative solutions, with regard to the installation of the N.G. supply network in the building, as for example the InWall solution proposed in "High-efficiency and low-environmental impact systems on a historical building in Rome: an InWall solution" [7]. In the South Europe, where the humidity in summer season has a medium-high value, it is common to provide new buildings with rain screen claddings. This technical solution disposes humidity and reduces building cooling loads [8]. In this way it is possible to install the N.G. supply pipes inside the ventilated cavity, in order to reduce the visibility and to always ensure a high dispersion degree of any leaks. Basing on these assumptions, the phenomenon of the N.G. dispersion inside ventilated cavities was analyzed to ensure safety against explosive atmosphere. At first, both the parametric and the CFD analysis were carried out. Finally the N.G. dispersion analysis in the air-gap was carried out using the rain screen cladding 3D model. For this purpose, it was implemented the mixture air-N.G. in the CFD software and it was introduced a N.G. source in the 3D model. The whole study contributes to define the preliminary design principles for rain screen cladding where N.G. supply pipes are installed.

## 2. Results and discussion

### *2.1. Parametric analysis*

A literature search was carried out in order to highlight the main variables that affect the air flow in ventilated cavities. Many authors investigated the matter as for example Ciampi et all, in "Ventilated facades energy performance" [8], who report the following equation:

$$W_0^2 = gL\sin\theta\left[1 - T_0\left\langle\frac{1}{T}\right\rangle\right]\left[\frac{\lambda_{in}-1}{2} + \frac{L\lambda\overline{T}}{2DT_0} + \frac{\lambda_{out}+1}{2}\frac{T_L}{T_0}\right]^{-1} \tag{1}$$

Table 1 Nomenclature

| Nomenclature | |
|---|---|
| D hydraulic diameter (m); | T0 outdoor air temperature in the shade and air temperature at duct inlet (K) |
| g acceleration due to gravity (m $s^{-2}$); | TL air temperature at duct outlet (K) |
| L :length of air duct (m); | T =T(x) : air temperature (K) |
| $\theta = 90$ | λ friction factor, dimensionless; |
| W0 air velocity at the duct inlet (m $s^{-1}$) | $\lambda_{in}$ and $\lambda_{out}$ friction factor at duct inlet and outlet, dimensionless |

The (1) formula allowed the authors to calculate the air velocity in the inlet section of the cavity, as a function of the geometric parameters and of the climatic conditions. In particular, the authors underline that the main geometrical parameter that affects W is the thickness of the cavity. From these results, it was decided to investigate how the phenomenon of the N.G. dispersion is affected by geometrical features of the ventilated wall and by the environmental conditions. The first step of the work examined the influence of the cavity thickness on the phenomenon. For this purpose, it has been carried out a first parametrical estimation of the velocity inlet section (W) using equation (1). In the Figure 1 the trends of W, both in summer and winter climatic conditions, were reported as a function of the cavity thickness. In Table 2 shows the input data used. It is noteworthy that, in both climatic conditions, the W is higher than zero. Moreover it is interesting to observe that the lower velocity values are in summer climatic conditions.

Table 2. Input data used

| | Summer | Winter |
|---|---|---|
| W all height L (m) | 3 | 3 |
| Width of the wall module l (m) | 1 | 1 |
| Inlet roughness λin | 0.5 | 0.5 |
| Outlet roughness λout | 1 | 1 |
| Walls roughness λ | 0.25 | 0.25 |
| Outdoor air temperature at shaded conditions T0 (°C) | 28 | 7 |
| Temperature of the wall in sunny position Te (°C) | 39 | 7 |
| Air temperature in outlet section $T_L$ | 34 | 13 |
| W all height L (m) | 3 | 3 |
| Width of the wall module l (m) | 1 | 1 |

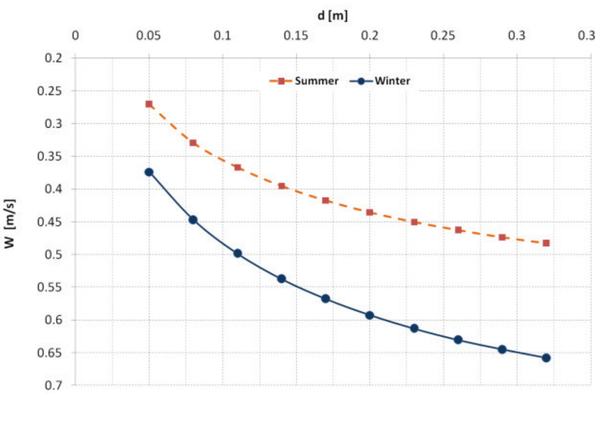


Fig. 1. W vs. d, in winter and summer climatic conditions

### 2.2. 2D and 3D fluidinamic analysis

The CFD analysis, produce both the spatial and time distribution of the fluid filtration main parameters. In particular the CFD analysis allows to estimate the trend of fluid velocity inside the analyzed control volume [9]. In order to investigate about the air velocity and the N.G. dispersion inside the cavity in the worst climatic conditions, the 2D and 3D CFD analysis were carried out in summer conditions. The 2D CFD analysis was carried out using the model shown in Figure 2.

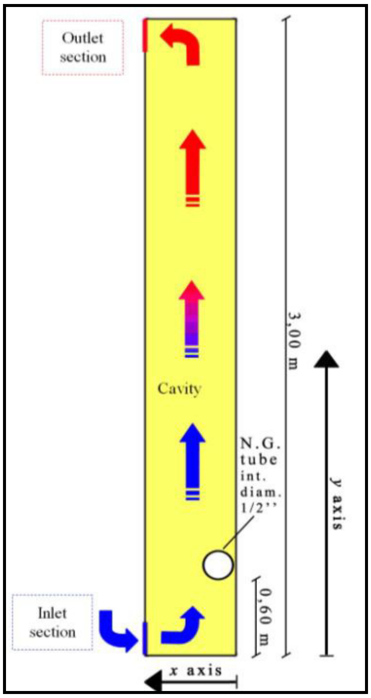


Fig. 2. 2D CFD Model.

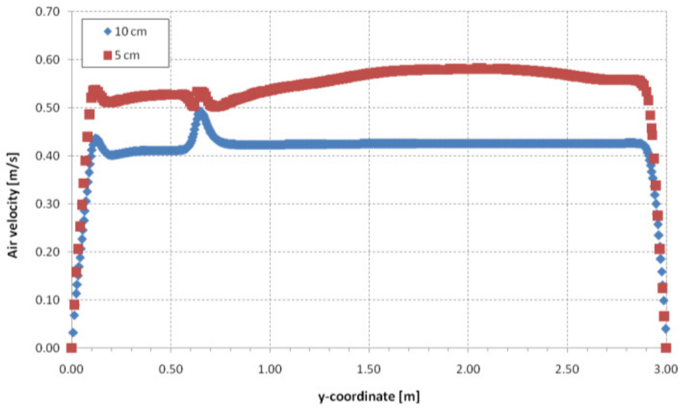


Fig. 3. Air velocity trend varying on y-coordinate (rain screen cladding height).

From the fluid dynamics point of view, the following assumptions and boundary conditions were considered (Table 3):

Table 3 Flow assumptions and Boundary conditions

| Flow assumptions and Boundary conditions |
|---|
| Incompressible ideal gas: density is a function of temperature ( Bousinesq assumption ) |
| Gas species: Air and Methane mixture |
| Turbulent flow : K-ε standard model in two equations |
| Boundary conditions |
| Outer wall temperature T1: 40°C |
| Inner wall temperature T2: 27°C |
| Inlet section: velocity inlet |
| Outlet section: out-flow condition (flow exits without set conditions) |

In order to guarantee both, better resolution and reduced computing time, it was adopted an uniform grid. In the 2D model, the grid spacing in x and y directions is 1 cm. The velocity inlet was fixed as a function of the cavity thickness. In detail, the velocity inlet was estimated by the Equation 1, in function of the cavity thickness. The Figure 1 shows how in summer climatic conditions there are the lower velocity values. In order to analyze the air velocity in the worst conditions, the velocity inlet was fixed to 0.28 m/s and 0.36 m/s, with interspaces thickness of 5 cm and 10 cm respectively. In the Figure 3, the air velocity trend were reported for two rain screen cladding models, with different interspace thickness: 5 cm and 10 cm. Subsequently the N.G. dispersion analysis have been carried out in order to evaluate how the W affects the dispersion of N.G. The N.G. used in civil field in Italy is mainly composed by $CH_4$, and by a fraction reduced by additional chemical compounds [10]. Basing on this assumption, it was considered appropriate to overlook the contribution of the other components in this dissipation phenomenon, considering only the CH4. In the model of the wall shown in Figure 2, there is a N.G. tube from which it is supposed a gas leak of 9*10-8 kg/s. In this way it is possible to simulate a leak of CH4 of low entity, hardly detectable by electronic devices for civil use. The following table shows the trend of CH4 Mass Fraction as a function of the air gap thickness.

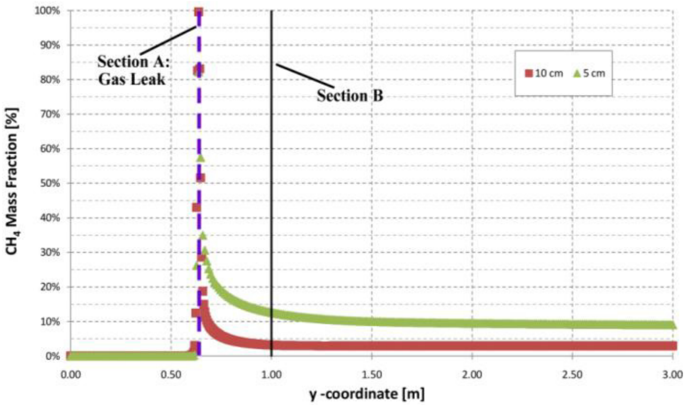


Fig. 4. $CH_4$ mass fraction vs. y-coordinate, in case of 5 and 10 cm thickness.

As shown in Figure 4, the increase of the interspace thickness, produces a greater dispersion of $CH_4$ in the cavity. In particular with 10 cm thickness, at 40 cm from the gas leak point, the $CH_4$ Mass Fraction is about 5%. In order to increase the accuracy of the results, a 3D CFD analysis was conducted using the model shown in Figure 5, considering a rain screen cladding of 1 m width. The hypothesis and the boundary conditions is equal to 2D model, moreover, the grid spacing in x, y and z directions is equal to 1 cm. In Figure 6 it was reported the trend of $CH_4$ molar concentration in 3D model. The Figure 7 shows the trend of $CH_4$ molar concentration both in 2D and 3D Models. It is interesting to observe a good agreement between the two trends. In particular, it is noteworthy that molar concentration is higher using the 2D model. This mismatch is amplified with the increasing of the distance from the source of emission of N.G. The numerical results show how in both summer and winter conditions, the velocity inlet is higher than zero. Consequently, in case of small flows of methane, the natural air flow inside the cavity, produces a notable reduction in the $CH_4$ molar concentration. In order to conform the theoretical results, it will be carried out an experimental analysis in a further work. The numerical results show how in both summer and winter conditions, the velocity inlet is higher than zero. Consequently, in case of small flows of methane, the natural air flow inside the cavity, produces a notable reduction in the $CH_4$ molar concentration. In order to conform the theoretical results, it will be carried out an experimental analysis in a further work.

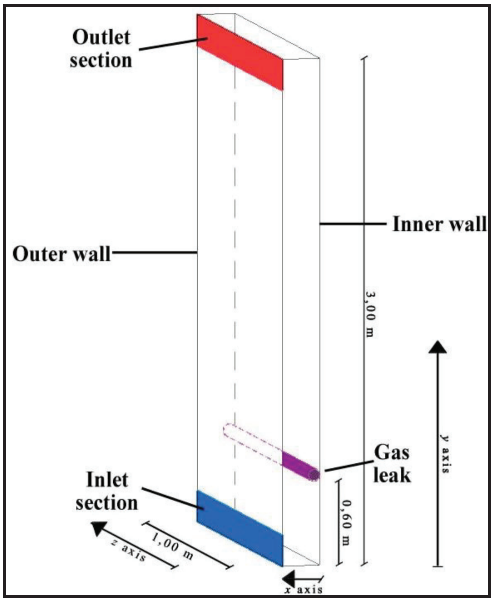


Fig. 5. 3D CFD Model.

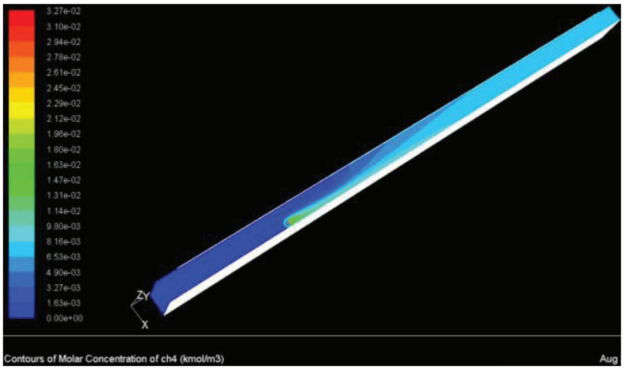


Fig. 6. The trend of $CH_4$ molar concentration in 3D model

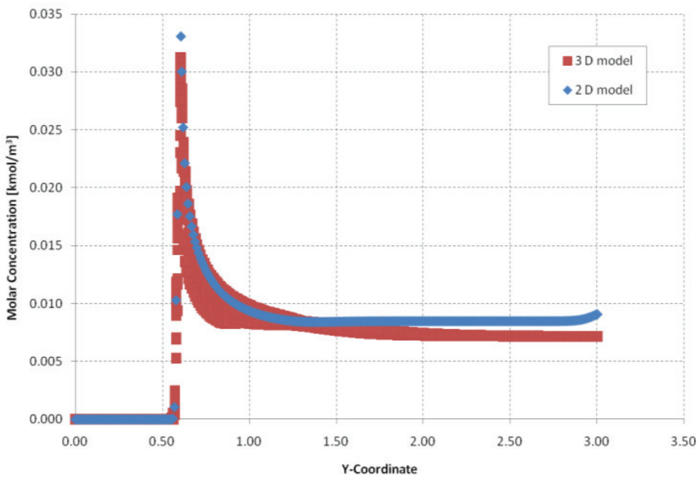


Fig. 7. 2D CFD and 3D CFD results: molar concentration.

## 3. Conclusion

The work carried out allowed to evaluate the N.G. dispersion inside ventilated cavities, in order to ensure high safety standards. The results obtained show how the thickness of the interspace is one of the parameters that most influences the dispersion of gas in the cavity. In detail, an increase of 50% of the thickness, implies a reduction of about the 65% of the CH4 Mass Fraction, at the farther away point from the N.G. leak point. Going into the specific of the CFD analysis, the 2D model overestimates the CH4 molar concentration in the natural ventilated cavity, compared to the 3D model. In detail, the discrepancy is lesser than 25%. In any case, the trend of the 2D and 3D models are in good agreement. The lower values of the CH4 molar concentration in the 3D model, are due to taking in consideration the third component of dispersion tensor (z axis).The results obtained show that, in case of small flows of methane, the natural air flow inside the cavity, produces a notable reduction in the CH4 molar concentration. It is noteworthy that at 40 cm from the N.G. leak point, the CH4 molar concentration reduction amounts to 70%.In order to achieve a greater degree of knowledge of this phenomenon, some experimental measurements on a rain screen cladding prototype, will be carried out in a further work.

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